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DESIGN OF LASER OPTICAL SYSTEMS

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FOREIGN TECHNOLOGY DIVISION

# HUMAN TRANSLATION

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TITLE: DESIGN OF LASER OPTICAL SYSTEMS

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SUMMARY This article gives basic rules associated with Gaussian beam transforms in optical systems. It discusses optimum selections for system light passing aperture diameters, and, after researching Gaussian beam diameter system intercepts or truncations, produces rules for diffraction transformations.

When designing laser optical systems, it is necessary to study transformations associated with various types of optical instruments or systems with regard to Gaussian beams. This is in order to find out the rules or patterns for transmission and transformation. This is an important topic in the practical applications of lasers. It is also a key question in the design of top quality laser systems.

Discussions of lenses have to do with transformations of Gaussian beams, that is, finding out the beam waists or foci for beams before and after transformation (this includes the relationships between the locations of the beam waists or foci and the magnitude of waist or focal spots or striations). This article, first of all, sets up the basic rules associated with the transformations from optical systems to laser beams. In conjunction with this, it does research on system interceptions or truncations of Gaussian beam diameter systems[1], the rules of transformations after diffraction, and, at the same time, discusses the effects of aperture diameter on the magnitude of Gaussian beam diffraction spots or striations and their positions.

## II. CALCULATIONS OF THE DIMENSIONS OF THE EXTERIOR FORMS OF LASER OPTICAL SYSTEMS

In order to be able to alter optical systems associated with laser beam wave surface curvatures, when it is required to alter light beam divergence waves or light spot (or striation) diameters as well as when there is a need to do wavefront coupling examples for two waves, it is possible to make use of convergence systems, collimation systems, divergence systems, as well as Gaussian light beam wave surface coupling systems.

When lasers go through aperture diameters of limited dimensions (for example, various types of collimation and convergence lenses), if the dimensions of the light spots or striations associated with Gaussian beams for light apertures are very greatly larger as compared to the light aperture locations, it is possible to recognize that light beams go through without receiving limitations. Then, on output surfaces, it is nothing else than the Gaussian light beam light path distribution. As far as the light waist or focal dimensions and positions after transformation going through lens and other similar types of optical systems are concerned, they are capable of being operated upon in accordance with the procedures described below.

First of all, one calculates cofocal parameter values associated with laser beam space parameter resonance cavities

$$R_0 = 2L\sqrt{\frac{g_1 g_2 (1 - g_1 g_2)}{g_1 + g_2 - 2g_1 g_2}} \qquad (1)$$

In this equation, L is the distance between two lens surfaces of a resonance cavity or chamber

$$g_1 = 1 - (L/r_1)$$
$$g_2 = 1 - (L/r_2)$$

The radii of the two lens surfaces are capable, from cofocal parameter values, of precisely determining beam waist diameters

$$2W = 2\sqrt{\frac{\lambda R_0}{2\pi}} \qquad (2)$$

In the equation, $\lambda$ is the laser wavelength.

At any location which is a distance z from the beam waist, the diameter of the beam cross section is capable of being precisely determined from the equation below

$$2W_z = 2W\sqrt{1 - \varepsilon^2} \qquad (3)$$

In this equation, $\varepsilon = 2Z/R_э$ and is the coordinate corresponding to that cross section.

On any given cross section, it is possible, in approximate terms, to recongnize that the fronts of laser light beam waves are spherical surfaces of curvature radius R.

$$R = [(1 + \varepsilon^2/2\varepsilon] \cdot R_э \tag{4}$$

Making use of equations (3) and (4), it is possible to calculate the wave front radius of curvature within lens surfaces as well as light cross section radii. Following that, from the two equations below, one precisely determines the focal distance of thin lens components, radii of light passing apertures, as well as linear dimensions of other optical parts and the distances between them. They are as shown in Fig.1.

$$R_э' = \frac{R_э}{1 + (z/f')^2 + (R_э/2f')^2} \tag{5}$$

$$1 - \frac{Z'}{f'} = \frac{1 + Z/f'}{1 + (Z/f')^2 - (R_э/2f')^2} \tag{6}$$

If one takes beam waists as well as the beam waist images which are formed by optical systems, they are capable of being seen as acting as object and image. It is then possible, using the equation below, to calculate the beam waist dimensions and degree of divergence associated with laser beams after going through optical system transformations.

$$\beta_1^2 = \frac{4(f')\beta^2}{4(f') + \beta^2 R_э^2} \tag{7}$$

$\beta$ II(illegible) is the laser beam lateral rate of amplification.

$$\nu_1^2 = \frac{4(f') + \beta^2 R_э^2}{4(f')^2\beta^2} = \nu^2 + \left(\frac{R_э}{2f'}\right)^2 \tag{8}$$

$v_{II}$ is the laser beam rate of angular amplification.

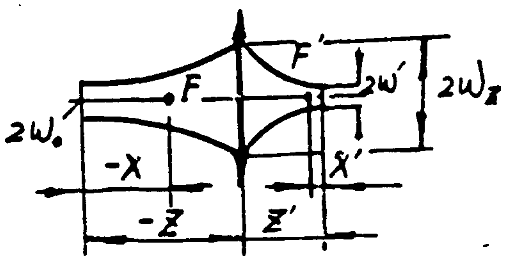


图1

Fig.1

## III. SELECTION OF LIGHT PASSING APERTURE DIAMETERS

The diameters of light passing apertures have an influence on Gaussian beam transformations. When Gaussian beams go through a round aperture, if the diameter of the light aperture is much larger than the light aperture which is at the location of the Gaussian light beam's light spot or striation, it is possible to recognize that light beams do not suffer from limitations. On output surfaces, one has Gaussian beam output distributions. If the light aperture dimensions are relatively small, by contrast, due to light aperture limiations, it will produce diffraction effects. Within output surfaces, one no longer has Gaussian beam light strength distributions. When the diameters of the system's light passing apertures are very large, will laser beams not produce diffraction?

With regard to Gaussian light beams being influenced by limitations from round aperture diameters, when $Z \gg 4\pi a^2/\lambda$, it is possible, on the basis of Fulanghebi (phonetic, possibly Furu Kawabi) diffraction diagrams, to make use of repeated amplitudes in order to approximately describe light fields,

$$f(u) = A\int_0^{2\pi}\int_0^{\infty} circ\frac{r}{a}\, e^{-2r^2/w^2} \cdot J_0(ru)rdr \qquad (9)$$

In this equation, $\exp(-a^2 r^2/w^2)$ is the light field amplitude distribution which obeys Gaussian rules or patterns within the range of a circular aperture with a radius a.

W is the basic mode light spot or striation precisely determined on the basis of a level reduced e fold in light field amplitude.

airc r/a is field function. $u=2\pi ap/\lambda Z$.

r is the radius within the aperture radius surface. p is the radius within the analytic surface. Z is the distance between the aperture diameter planar surface and the analytic planar surface. $J_0$ is a zero order Bessel function.

As far as altering the a/w ratio value is concerned, one takes equation (9) and uses computers to carry out calculations. In the diffraction diagrams, the strength distribution is related to the a/w limitations of light beams and is as shown in Fig.2. In the diffraction diagrams, the dimensions of the first dark ring are related to the ratio a/w.

$$D_{diffraction} = 2k_{II}\lambda/N_A \qquad D_{衍射} = 2k_{\mathrm{I}}\lambda/N_A \qquad (10)$$

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In equation (10), the relationship between coefficient $K_{II}$ and a/w is as shown in Table 1.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| a/w | 0.2 | 0.4- | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.8 | 2.2 |
| $k_{II}$ | 1.22 | 1.25 | 1.28 | 1.31 | 1.42 | 1.55 | 1.74 | 3.12 | 3.73 |

Table 1

From the Table, it is possible to know that, when a/w = 1, the angular location of the first dark diffraction ring ought, according to the $\varphi = 1.43\lambda/D$ formula, have its calculations carried out.

When the projected beam waist dimensions are unusually small as well as when light beams are limited by aperture diameters associated with objective lenses, it is necessary to take the increase in the dimensions of the light spot or striation formed by the difference between diffraction and image to carry out calculations. With regard to the generality of focusing systems, the dimensions of light spots or striations for this time are capable of being determined by the equation below:

$$D' = D_1' + D'_{\text{衍射}} + 2\delta_T' \tag{11}$$

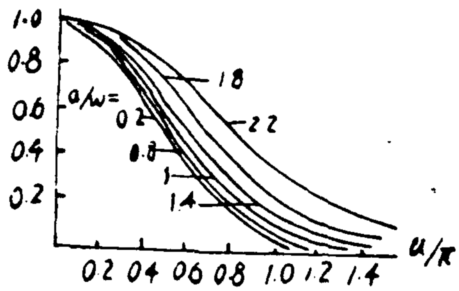


Fig.2 (1) Relative Units

In equation (11), $D'_1$ is the diameter of the ideal focused light spot or striation. $D'_{Diffraction}$ is the diffraction light spot or striation. $\delta'_T$ is the vertical or perpendicular spherical aberration.

With regard to laser optical systems that have diffraction effects, $K_{II}$(illegible) values selected for calculating the diffraction spot or striation diameters can be found in Table 1. Different values were selected on the basis of different magnitudes for the diameters of light passing apertures. An example is laser scanning systems. In order to satisfy scanning resolution requirements, in the equation N=L/d, L is the light point diameter. When designing the system in question, it is necessary to appropriately select the focal distance for image forming lenses as well as diameters for light passing apertures. When f' is fixed, the larger a/w is, the larger is the diameter of the light spot or striation diameter. When a/w is reduced in size due to light aperture limitations, light spot diameters become smaller. However, energy comsumption is great. As a result of this, one should appropriately select aperture diameters.

When designing laser optic systems, if one opts for the use of very large light passing aperture diameters, is it possible to ignore diffraction effects? Discussing the effects of round aperture diffraction on Gaussian beam characteristics has practical significance.

When Gaussian light beams, in round shaped light diaphragms, give rise to diffraction, the distribution of light flux is capable of being solved for according to the formula described below

$$(ru)rdr\int^{2}udu \qquad (12)$$

In the equation, $\Phi$ is the light flux passing through the aperture diameter. $\Phi_0$ is the total light flux.

On the basis of different values of a/w, one takes equation (12) and carries out calculations. The results are set out in Table 2.

| $a/w$ | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.2 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\phi/\phi_0$ | 84.2 | 86.0 | 88.8 | 92.1 | 95.3 | 97.8 | 99.0 | 99.6 | 99.8 | 100 |

Table 2

From Table 2 it is possible to know that the magnitude of the diameter of the aperture passing light influences the light flux going through lasers, giving rise to different levels of diffraction effects. When a/w=1, it is only possible to put through 95.3% of the light flux. When $a \geq 1.5W$, it is possible to put through 99%. Normally, one selects a light passing aperture diameter of 2a equal to 3 W, designating this time to be the optimum light passing aperture diameter. According to this aperture design, it is possible to ignore the diffraction distortions produced by the system in question. When $a/w < 1.5$, the system design must necessarily consider Gaussian light beam diffraction effects.

## IV. FOCAL POINT DISPLACEMENT IN THE FOCUSING OF GAUSSIAN LIGHT BEAMS[2,3]

In the design of Gaussian wave surface coupling systems, it is necessary to consider focal point displacements associated with focusing Gaussian light beams. Discussing the use of a thin lens with a focal length of f' to focus a monochromatic Gaussian light beam, assume that the beam waist is located on the plane of the lens. On the plane of the lens in question, there is a round field aperture with radius a , causing the light beam not to receive limitations going through lens focusing. After focusing, the maximum light strength of the Gaussian light beam most certainly is not located at the geometrical focus. However, it is at the point P relatively close to the focal lens. As is shown in Fig.3, as far as the displacement of the deviated so-called focal point relative to the focal point located at the beam waist point P after formation of the image is concerned, the values are capable of, respectively, using two parameters to be expressed, $N_W$ or $N_a$, collectively designated as Fresnel numbers. Using $N_W = W^2/\lambda f'$ to express the formula for calculating the focal point displacement, it is 17

$$\Delta f' = f'(1 + \pi^2 N_W^2) \tag{13}$$

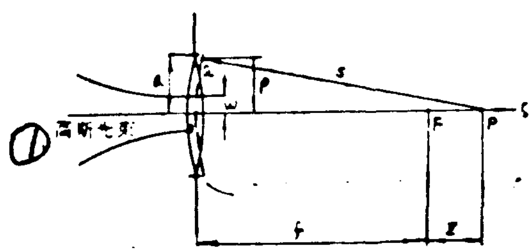


Fig.3 (1) Gaussian Light Beam

The formula for calculations associated with using $N_a = a^2/\lambda f$ to represent focal point displacement is

(14)

The results of calculations according to equation (14) are capable of obtaining the relationships between $\Delta f'$ and $N_a$ as shown in Fig.4.

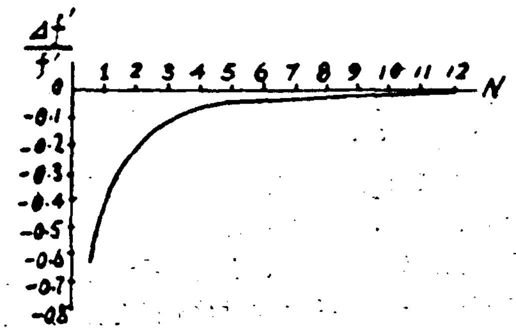


Fig.4

From the Fig., it is possible to see that, following along with a reduction in the Fresnel number $N_a$, $\Delta f'/f'$ speeds increase. When $N_a$ = 12, $\Delta f'/f'$ is 1%. When $N_a$ = 3, $\Delta f'/f'$ is 10/%. When N = 1(unclear), $\Delta f'/f'$ is 40%.

When Gaussian light beams radiate into lenses, they receive an intercept or truncation from the lens light aperture. The light field distribution in the vicinity of the focal surface behind the lens is capable of being expressed by the use of the equation below

$$U(P) = iA\left(\frac{\pi N_a - u}{f'}\right)\exp \tag{15}$$

$$\left(ikf'\frac{u}{\pi N_a - u}\right)\frac{\exp(-a - iu) - 1}{a + iu} \quad (15)$$

In the equation, a = $(a/w)^2$ is designated as being the Gaussian light beam's intercept or truncation coefficient. u(z) = $\pi$ $N_a$ z(f'+z) is the parameter that precisely determines the point P on the X axis.

The light strength of point P

$$I(p) = I(F)\left(1 - \frac{u}{\pi N_a}\right)^2 \frac{a^2}{a^2 + u^2} \cdot \frac{\cosh a - \cos u}{\cosh a - 1} \tag{16}$$

In the equation

$$I(F) = (\pi |A| / f')^2 (1 - e^{-a})^2 N w^2 \tag{17}$$

I(F) is the light strength of focal surface F' behind the lens.

In order to solve for the location of the point P of maximum strength, it is possible to solve the equations set out below

$$\frac{dI}{dz} = \frac{dI}{du}\frac{du}{dz} = 0 \tag{18}$$

$$\frac{dI}{du} = -\frac{IF}{\pi N_a(\cosh a - 1)}\left(1 - \frac{u}{\pi N_a}\right) \frac{a^2}{a^2 + u^2} \times \left[2\frac{a^2 + \pi N_a u}{a^2 + u^2}(\cosh a - \cos a) - (\pi N_a - u)\sin u\right) \tag{19}$$

It is possible to prove that it is not possible for du/dz to be zero. From equation (19), it is possible to obtain the equation

$$\frac{2}{\pi N_a}\left(\frac{a^2 + \pi N_a u}{a^2 + u^2}\right)(\cosh a - \cos u) = \left(1 - \frac{u}{\pi N_a}\right)\sin u \tag{20}$$

Solving this equation, it is possible to obtain quite a few roots. Among these, it is necessary to have a maximum $u_m$. Let $Z_m = \Delta f'$. From equation (15), it is possible to obtain

$$\Delta f'/f' = \varepsilon_m/(\pi N_a - \varepsilon_m) \qquad (21)$$

When $N_a \gg N_W$, there is relatively weak light beam intercept or truncation. From equation (15), it is possible to obtain $\Delta f'/f' = 1/(1+\pi^2 N_W^2)$. This and (13), described before, are in line with each other.

When $N_a \ll N_W$, there is very strong light beam intercept or truncation. It is possible, on the basis of equation (19), to solve for $\Delta f'/f'$.

## V. CONCLUSIONS

1. In the design of laser optic systems, when a/w is larger than 1.5, as far as the system is concerned, it is possible to ignore the effects of diffraction. According to the basic rules for Gaussian light beam transformations, one makes use of knowledge in geometrical optics to carry out design. 18

2. When a/w is smaller than 1.5, it is necessary to consider diffraction effects. On the basis of diffraction theory, one considers the light strength distribution at the image point in order to precisely determine the system image formation requirements, carry out design, and evaluate.

3. With regard to the design of wave surface coupling systems, it is necessary, on the basis of the magnitude of Fresnel numbers, to precisely specify the amount of focal point displacement associated with systems. As a result of this, on obtains the optimum match up.

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